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AFFDL ltr, 31 May 1973

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HIGH ALTITUDE CRITICAL ATMOSPHERIC TURBULENCE DATA SYSTEM

J. P. BOONE

TECHNICAL REPORT No. AFFDL-TR-67-1

MAY 1967

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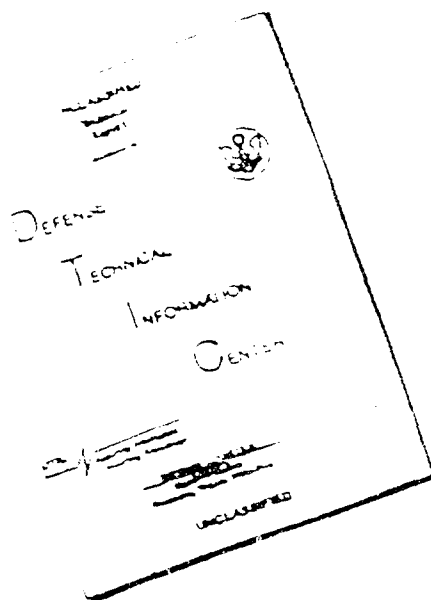
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(6) **HIGH ALTITUDE CRITICAL ATMOSPHERIC TURBULENCE DATA SYSTEM**.

(1) Final technical rept 15 Feb 65 - 10 Feb 66,

(10) Joseph P. BOONE

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FOREWORD

The material in this report is largely a compilation and summary of reports formulated by Lockheed-California Company. The work presented was performed by Lockheed under Contract AF33(657)-11143. Contract AF33(657)-11200 was monitored by Mr. Neal V. Loving and Mr. Joseph P. Bo ne of the Experimental Mechanics Branch, Structures Division, during the period 15 February 1965 to 10 February 1966. Mr. Richard Quist of Lockheed was the principal contributor to the technical content of this report.

This technical report has been reviewed and is approved.

JAMES C. HORSLEY, JR., Major, USAF
Chief, Experimental Mechanics Branch
Structures Division

ABSTRACT

The purpose of this report is to provide a synopsis of the data system designed to measure, record, and process High Altitude Critical Atmospheric Turbulence (HICAT) data.

The HICAT Project is to measure gust velocity components in the altitude range of 40 to 70 thousand feet in several world areas. The goal is a statistical definition of the "roughness" of the atmosphere which can be applied to design requirements for advanced aircraft structures.

A Pulse Code Modulation airborne system is described. Highly accurate sensors and components, including an inertial platform, are used aboard a WU-2 test aircraft in an attempt to resolve fine scale forces, accelerations, and aircraft motions in the atmospheric gust field. The magnetic tapes and other pertinent information are sent to a data processing ground station for generation of a computer-compatible tape, processing, and detailed analysis. Power spectral functions of the gust components are of major interest. Output data are correlated with meteorological and geographical data associated with the test site.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

The purpose of this report is to provide a synopsis of the data system designed to measure, record, and process High Altitude Critical Atmospheric Turbulence (HICAT) data. Reports offering greater detail in the areas of airborne instrumentation, data processing, and data analysis are listed in the References.

The HICAT Project is to measure gust velocity components in the altitude range of 40 to 70 thousand feet in several world areas. The HICAT Project is one of six turbulence projects being conducted by the Air Force Flight Dynamics Laboratory under the ALLCAT Program, ADP 682E (Reference 1). Each of the projects is associated with a particular altitude band in the total region of 0 to 200,000 feet. The goal is a statistical definition of the "roughness" of the atmosphere which can be applied to design requirements for advanced aircraft structures.

The HICAT airborne instrumentation originally consisted of a Frequency Modulation recording system and associated transducers (Reference 2). This system was used from April 1964 to 15 July 1964 to collect turbulence data having wavelengths from 60 to 2,500 feet. On 15 February 1965 the project was redirected to upgrade the instrumentation system in order to collect additional data with greater accuracy and to measure turbulence having wavelengths of 60,000 feet. A Pulse Code Modulation airborne system was selected and is described in this report. Highly accurate sensors and components, including an inertial platform, are used aboard a WU-2 test aircraft in an attempt to resolve fine scale forces, accelerations, and aircraft motions in the atmospheric gust field. It is possible to measure atmospheric wavelengths of 60,000 feet with a resolution of 1 foot per second. The upper frequency is limited to 5.0 CPS.

The magnetic tapes and other pertinent information are sent to a data processing ground station for generation of a computer-compatible tape, processing, and detailed analysis to aid in the definition of turbulence. Power spectral functions of the gust components as well as root-mean-square intensity distributions are plotted. Correlation and coherence functions are also possible. These quantities are correlated with meteorological and geographical data associated with the test site.

This report is organized to cover the problem of measurement, airborne instrumentation, data processing equipment, and data analysis.

SECTION II

THE MEASUREMENT PROBLEM

An aircraft is used as the test bed for the instruments needed to measure atmospheric gust velocities. The basic instruments selected to sense the gust force are a pair of vanes — — a "normal-force" vane and a "side-force" vane. These vanes attached to specially constructed strain gaged beams on a gust probe, are attached to the aircraft nose boom (see Figures 1 and 2). Obviously, the aircraft itself will respond to gust forces with translational and rotational motions.

These motions of the test aircraft and resulting inputs to the vane system must be separated from those forces on the vanes caused only by the gust.

This can be expressed as follows:

$$W_G = W_P + W_A$$

W_G = velocity of air relative to space, or gust velocity

W_P = velocity of air relative to the probe

W_A = velocity of the probe to space

For the vertical component, this can be described by the aircraft parameters as follows (Reference 3):

$$W_{G_{(z)}} = V_T\,(\theta - \alpha) - V_T\,\beta\phi + W_{A_{(z)}} + \ell\,\frac{d\theta}{dt}$$

$$= V_T\,\gamma - V_T\,\beta\phi + W_{A_{(z)}} + \ell\,\frac{d\theta}{dt}$$

$W_{G_{(z)}}$ = vertical velocity of gust (referenced to inertial frame)

V_T = true airspeed

α = aircraft angle of attack

θ = angle of pitch

γ = $\theta - \alpha$, flight path angle

β = angle of sideslip (derived from the force measured on the side-force vane)

2
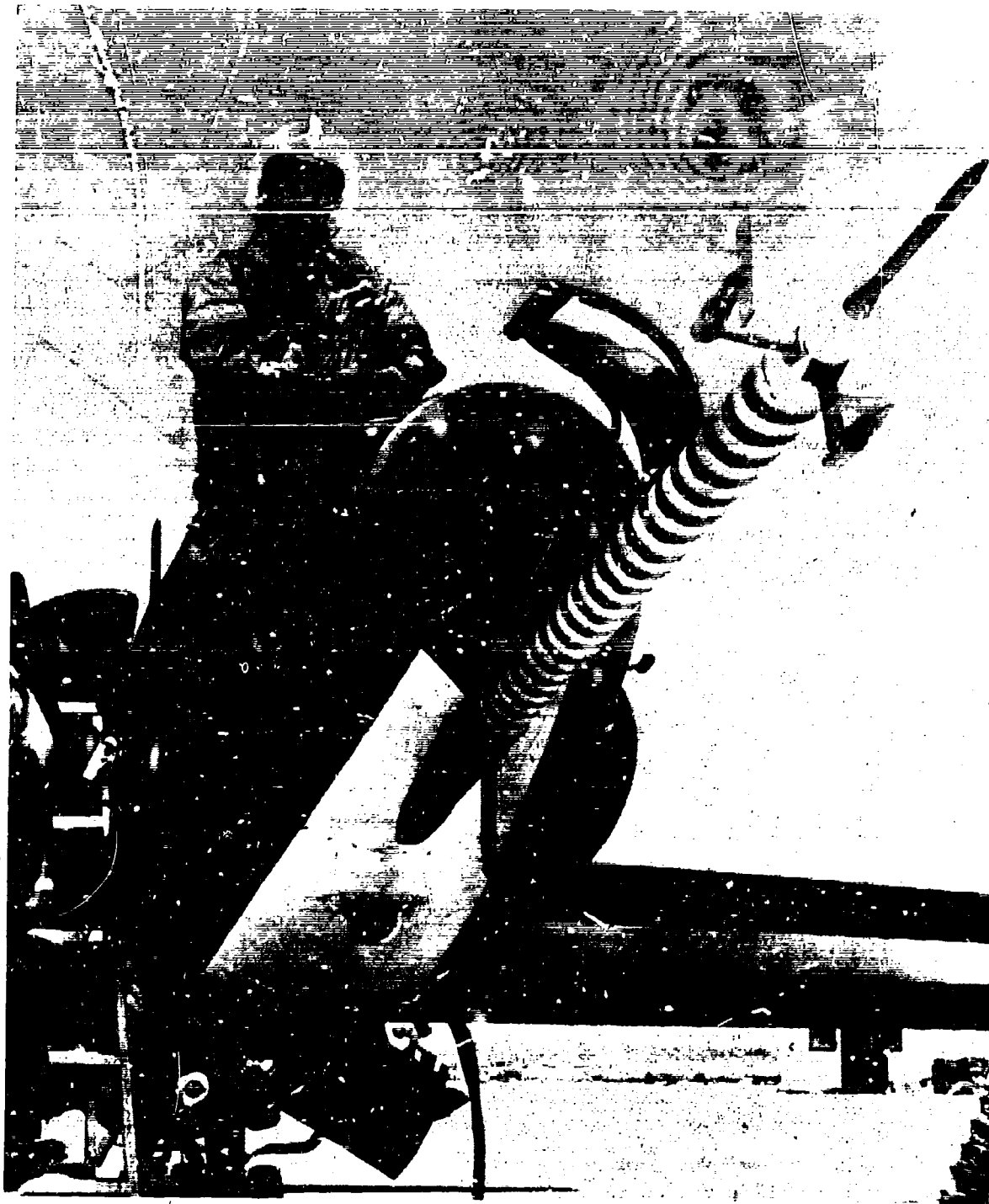
Figure 1   Aircraft Nose Boom

NOSE BOOM

LATERAL GUST
SENSOR (SIDE—FORCE
VANE)

STRAIN GAGES

STRAIN GAGES

VERTICAL GUST SENSOR
(NORMAL-FORCE VANE)

PITOT – STATIC TUBE
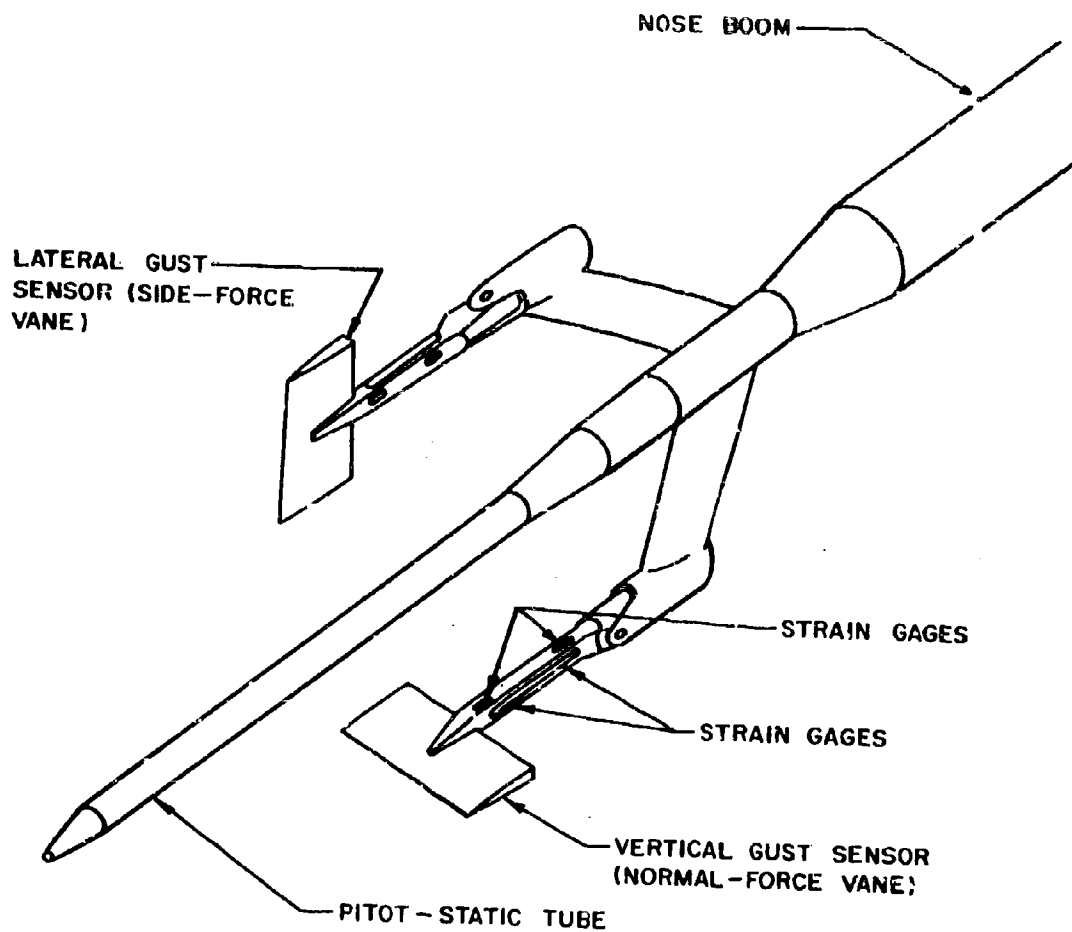
Figure 2   Vane Gust Sensors

4

ϕ = angle of roll (positive, right wing down)

$W_{A_{(z)}}$ = vertical velocity of aircraft (referenced to inertial frame)

ℓ = distance from aircraft CG to probe sensor

NOTE: The equation above for gust velocity assumes that angles are small and can be expressed directly in radians. It is also assumed that boom bending is small and that boom vibrations are above the frequency of interest.

The $W_{A_{(z)}}$ term is found by integrating the aircraft normal acceleration:

$$W_{A_{(z)}} = \int_{t_1}^{t_2} \left[a_z \cos\theta \cos\phi - a_y \sin\phi \cos\theta + a_x \sin\theta \right] dt + C_1$$

The a_z term is the CG accelerometer output with 1.0g component removed.

$\cos\theta \cos\phi$ accounts for accelerometer tilt.

The a_y term is a lateral component input to the vertical accelerometer.

The a_x term is a longitudinal component input to the vertical accelerometer.

C_1 is the initial velocity condition.

The $\ell \dfrac{d\theta}{dt}$ term accounts for pitching rate of the vane sensors relative to the aircraft center of gravity.

If the assumptions are made that:

a. sinusoidal atmospheric wavelengths of 60,000 feet are to be measured

b. resolution of 1 foot per second (peak-to-peak) is desired

c. aircraft true airspeed is 600 feet per second, the requirements for accuracy in the gust equation above can be determined, for example:

$$a_z = \frac{d}{dt}(W) = \frac{d}{dt}(0.5 \sin \omega t)$$

$$\omega = 2\pi \frac{600}{60,000} \text{ rad/sec}$$

$$a_z = \omega 0.5 \cos \omega t = \frac{2\pi \dfrac{600}{60,000}}{\dfrac{32.2 \text{ ft/sec}^2}{g}} \quad 0.5 \cos \omega t$$

$$a_z = .001 \cos \omega t \,(g's)$$

5

Therefore, a resolution of one milli-g must be obtained from the CG accelerometer. Similar analysis shows that angles must be resolved to .05 degrees of arc. Correspondingly low drift rates are required for the equipment to make these measurements.

On this basis, a digital instrumentation system was selected to be carried aboard the WU-2 aircraft (Reference 4). This system measures and records the gust velocity data in compact form on magnetic tape. An oscillograph is also installed on board the aircraft so that a quick-look analog record is available immediately after each flight. This record is used for determination of U_{d_G} * values by manual methods and is also used for trouble-shooting purposes in the field. The magnetic tape, edited oscillograph record, pilot reports, and other pertinent information are sent to the data processing ground station for generation of a computer compatible tape and further processing. (See Figure 3).

SECTION III

INSTRUMENTATION SYSTEM

The basic measurement list is tabulated in Table I. These measurements fulfill the measurement, analysis, and operational requirements for the HICAT Program. The transducers selected are of various types depending on the phenomenon to be measured. The major new transducer element in the system is a stable inertial platform which provides the required high accuracy attitude measurements and also highly accurate vertically stabilized acceleration measurements. The aircraft digital instrumentation system block diagram is shown in Figure 4. The airborne system volume and weight are approximately 15 cu. ft. and 450 lbs., respectively.

1. TRANSDUCERS

The Gust Probe developed and successfully employed with the Frequency Modulation System is used to make the sensitive airspeed and normal and lateral gust sensing vane force measurements required for the determination of true gust velocities (Reference 5). These gust velocities are detected by the change in lift produced on small fixed-vane sensors, which consist of light weight wedge shaped vanes attached to specially constructed strain-gaged beams (Figures 5 and 6). The angle of incidence of the vane with respect to the longitudinal axis of the aircraft remains fixed even when lift forces are imposed on the vane. Thus the vane measures shear forces instead of bending strain. The Statham strain gage type airspeed transducer senses dynamic and static pressures from the boom and provides an output to determine the longitudinal gusts.

A Litton LN-3 navigation system is installed on-board the aircraft. The inertial platform provides precise determination of aircraft attitudes in pitch, roll and heading, and acceleration
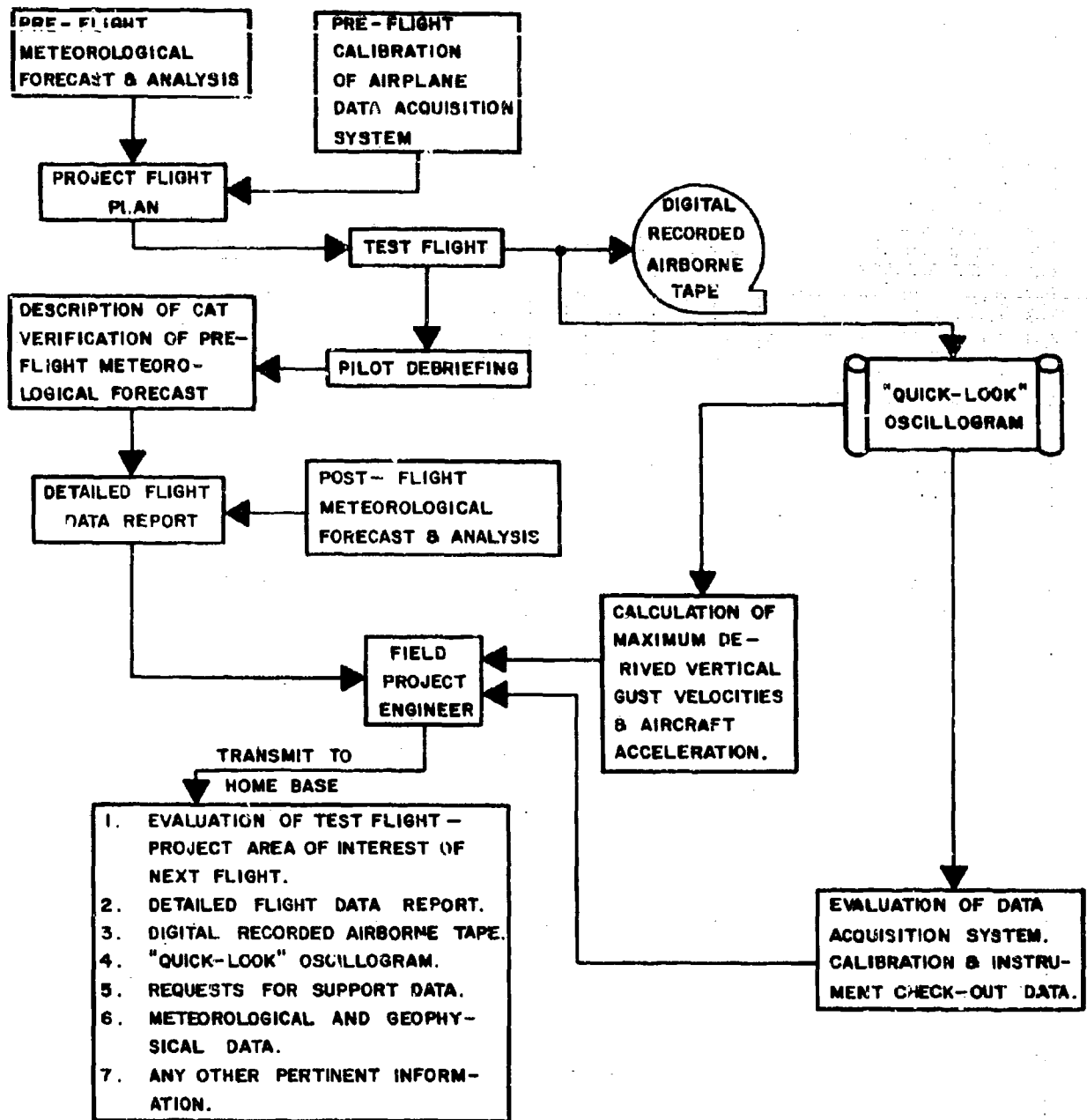
* Derived equivalent gust velocity.

Figure 3   Information Flow at the Field Site

TABLE I

HICAT MEASUREMENT PARAMETERS

Measurement	Location	Approximate Meas. Range	Required Resolution	Vendor/ Manufacturer	Model No.	Remarks
1. Alpha-Vane Normal Force[1]	Probe	±2 lb.	.004 lb.	Lockheed	FT	Note 5
2. Beta-Vane Normal Force[1]	Probe	±2 lb.	.004 lb.	Lockheed	FT	Note 5
3. Probe Normal Accel.[1]	Probe	-2, +4 g	.006 g	United Controls	PAL-5655-2B	
4. Probe Lateral Accel.[1]	Probe	±3 g	.006 g	United Controls	PAL-5655-1B	
5. C.G. Normal Accel.[1,2,3]	FS 408	-.5, +2.5 g	.003 g	United Controls	PAL-5655-3C	
6. C.G. Longitudinal Accel.[1]	FS 408	-.5, +.5 g	.001 g	United Controls	PAL-5655-4B	
7. Left Wing Nodal Accel.[3]	FS 175	-.5, +2.5 g	.003 g	United Controls	PAL-5655-3C	
8. Right Wing Nodal Accel.[3]	FS 175	-.5, +2.5 g	.003 g	United Controls	PAL-5655-3C	
9. Indicated Airspeed[1,2]	Probe	100-200 K	.3 Knot	Statham	PL283TC-1-350	Note 5
10. Pressure Altitude[3]	Nose	0-80 k ft	500 ft	Statham	P96D-15-500	Note 5
11. Pressure Altitude[1,2]	Nose	46-80 k ft	100 ft	Rosemount	830G1	
12. Incremental Pressure Altitude[1]	Nose	(.125 psi)	6 ft	Rosemount	830G1 +521A	
13. Total Temperature[1]	Nose	-80 to 0°C	.08°C	Rosemount	510V6	
14. Pitch Rate[1]	Nose	±10°/sec	.02°/sec	R. C. Allen	F2880-045	
15. Roll Rate[1]	Nose	±10°/sec	.02°/sec	R. C. Allen	F2880-045	
16. Yaw Rate[1]	Nose	±10°/sec	.02°/sec	R. C. Allen	F2880-045	
17. Left Aileron Position[3]	L Wing	±15°	.03°	Giannini	85172S-93	Note 5
18. Elevator Position[3]	Tail	-15°, +30°	.05°	Giannini	85172S-93	Note 5
19. Rudder Position[3]	Tail	±30°	.06°	Giannini	85172S-93	Note 5
20. C.G. Lateral Accel.	FS 408	-.5, +.5	.001 g	United Controls	PAL5655-4B	
21. Pitch Angle[1]	Q-Bay	±10°	.02°	Litton	LN-3	Note 6
22. Roll Angle[1]	Q-Bay	±10°	.02°	Litton	LN-3	Note 6
23. Yaw Angle[1]	Q-Bay	±10°	.02°	Litton	LN-3	Note 7
24. Heading (360°)[4]	Q-Bay	±180°	.36°	Litton	LN-3	Note 7
25. Vertical Accel.[3]	Q-Bay	-.5 +2.5 g	.003 g	Litton	LN-3	Note 5
26. X Velocity[4]	Q-Bay	±1000 ft/sec	2.0 ft/sec	Litton	LN-3	Note 5
27. Y Velocity[4]	Q-Bay	±1000 ft/sec	2.0 ft/sec	Litton	LN-3	Note 5
28. X Distance[1,4]	Q-Bay	±500 mi	1.0 mi	Litton	LN-3	Note 8
29. Y Distance[1,4]	Q-Bay	±500 mi	1.0 mi	Litton	LN-3	Note 8

(Measurements 25-29: LN-3 Platform)

1. Required for gust velocity determination. Measurement ranges and resolutions are those required to provide 1/2 ft/sec. (.3 knot) gust velocity resolution.

2. Required for derived equivalent gust velocity (U_{d_e}) determination.

3. Required for aircraft response analysis and probe calibration.

4. Required for determination of ground track and flight level wind velocities.

5. Through CEC 1-361-0001 DC Amplifier.

6. Through Natel D6006-763-CS-400-26-A Demodulator.

7. Through Natel D6006-781-CS-400-26-A Demodulator.

8. Through Litton RC18 Potentiometer and CEC 1-361-0001 DC Amplifier.
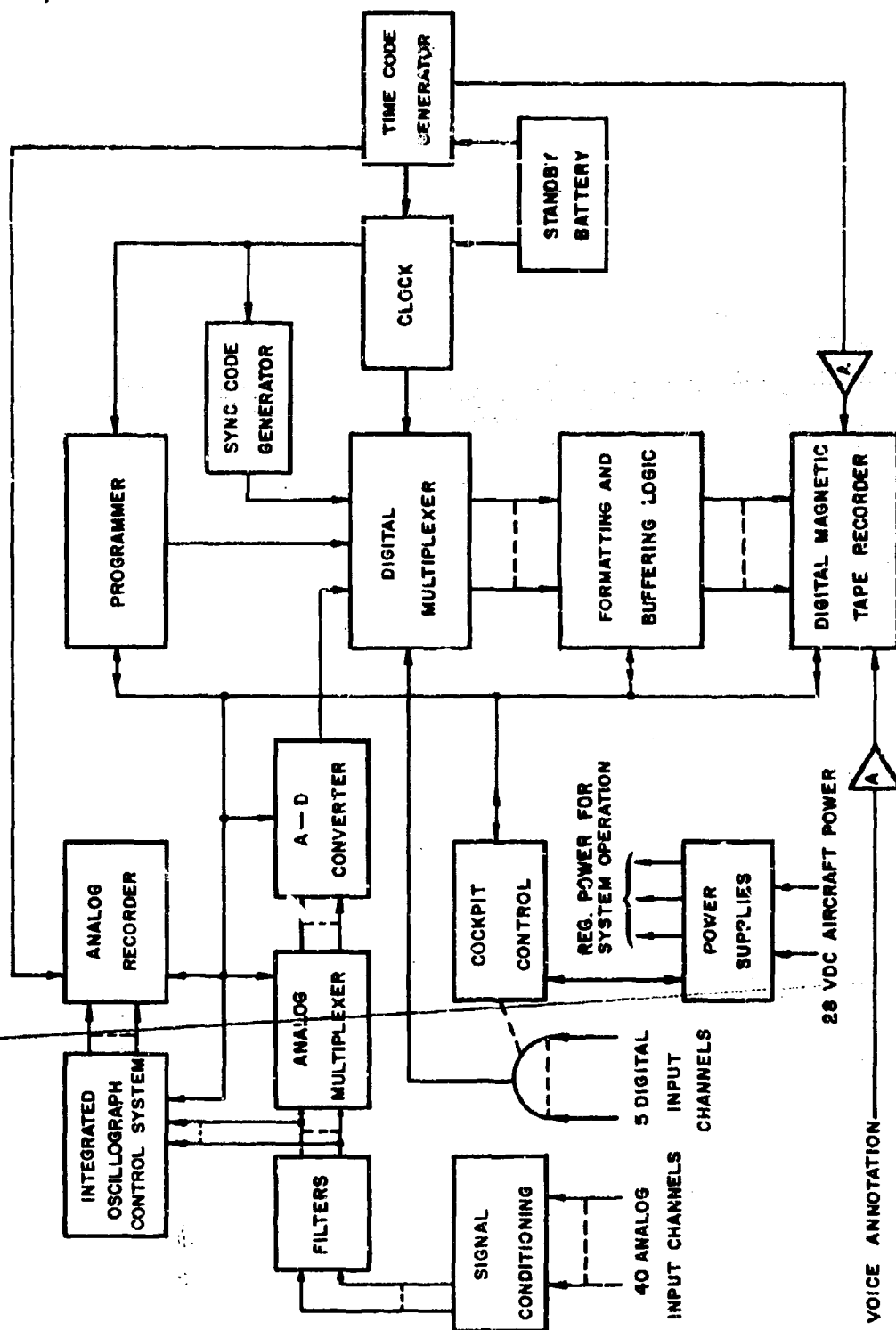
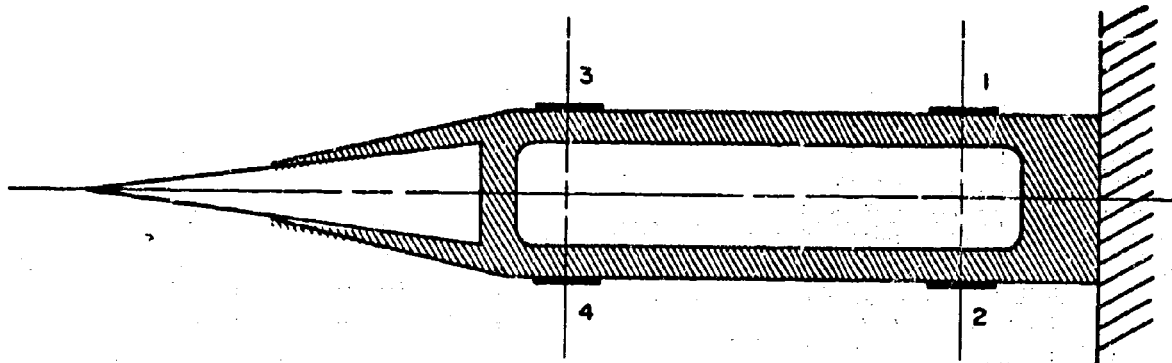Figure 4 HICAT Digital Instrumentation System

Figure 5   Double Beam Sensor with Strain Gage Installation for Shear Measurement
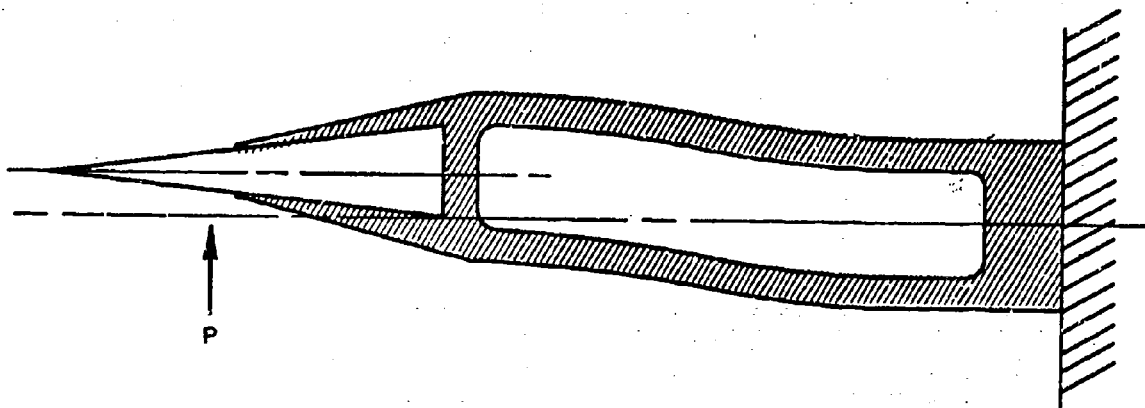

Figure 6   Double Beam Sensor Deflection Due to Airload

10

in the vertical direction. East-West and North-South velocity and distance information are also obtained from the LN-3 systems. The distance information is displayed in the cockpit and used extensively in flight patterns through turbulent areas.

In addition to the acceleration measurements available from the platform, similar measurements are taken at the gust probe, at the aircraft CG, and at the left and right wing nodal points in order to define motions of the boom in relation to the aircraft. For this purpose, force balance accelerometers, manufactured by United Controls, are installed. In these units, the seismic mass is loosely suspended and retained in position by a force electromagnetically developed from the seismic mass's position error. The restoration force, electrically measured, provides the output. The resolution and accuracy of these units are sufficient to eliminate the need for dual range or redundant sensors at particular locations.

Outside air temperature is measured with a Rosemount total temperature probe. This transducer was used on the earlier HICAT testing, and the recovery factor, time constant, and accuracy of this instrument are compatible with the requirements of the digital instrumentation system.

Altitude is determined with a Rosemount multi-range pressure transducer with one output for the overall range of 50,000 to 80,000 feet while a second output, automatically engaged, provides expanded scale measurements over 16 bands of the overall range. Coarse altitude is measured with a Statham strain gage type transducer over the range of 0 to 80,000 feet.

The rate gyros provided to obtain a direct measure of pitch, roll and yaw rates are manufactured by R. C. Allen. The output is an AC signal from a microsyn type pick off which is demodulated to a DC level for recording. Availability of these measurements provides a direct method of confirming the operation of other measurements in the field as well as a backup measurement to the heading and attitude information available from the stable platform.

Surface position measurements are made by high resolution Giannini potentiometers linked directly to the rudder, elevator and aileron control surfaces.

Ancillary signals may be used to describe such slowly or infrequently changing data as gear position, flap position, fuel consumption, flight plan index, and so forth. Five digital channels are available for this information to be entered directly into the digital multiplexer. Six decimal thumbwheel switches are located on the cockpit control panel. Each switch provides a 4-bit parallel BCD output code resulting in 24 discrete bits of digital information that can be entered into the PCM system format from the cockpit control panel. The remaining 26 bits making up the total of the 5 digital 10-bit words may be developed from external remote contact closures within the aircraft systems. The Rosemount multi-range altitude transducer is connected to 4 of these bit positions to indicate the particular band where the transducer may be operating. Signals from the LN-3 inertial platform and from a pilot operated "event" switch are also entered into the digital data format in this manner.

2. SIGNAL CONDITIONING

Some of the transducer signals require conditioning prior to the digital instrumentation system. The vanes, airspeed, coarse altitude, surface positions, and temperature measurements require amplification to voltage levels suitable for digitizing. CEC DC amplifiers were selected for this purpose. Some of the signals from the platform also require CEC DC amplifiers while others require demodulators to convert from AC to DC voltage levels and Natel amplifier-demodulator units were selected for this requirement. All signals are standardized to 0 to 5 volt limits with suitable voltage divider networks.

3. DIGITAL SYSTEMS (PCM)

The system selected for this requirement was manufactured by Dynatronics Incorporated, Orlando, Florida. General specifications are the capability of 40 analog and 5 digital input channels. The analog inputs are in the form of three wire differential signals consisting of a signal hot wire, a signal common wire, and a shield wire. Each analog input channel has a minimum of 60 db common mode noise rejection at a frequency of 0 CPS (DC) with a common mode noise voltage of up to 5 volts DC.

The conditioned transducer analog signals are passed through presampling filters, and associated buffer amplifiers, with a low pass characteristic to minimize aliasing errors. To prevent noise due to aliasing caused by transducer output signals in the frequency domain above the frequency of interest, it is necessary to provide low pass filters having cutoff characteristics tailored to certain practical requirements. The ratio of the sampling frequency to the cutoff frequency can only be lowered while making the cutoff characteristics more severe. This ratio is 25 samples per second-to-7 cycles per second for the HICAT case, whereas a ratio of 2 is the minimum theoretical value. The volume of data is proportional to this ratio when other factors remain fixed. The cost and complexity of low pass filters rises rapidly with increasing cutoff severity while maintaining quality. The contradictory requirements are best reconciled on an economic judgment basis. For the accuracy required for the HICAT Project, satisfactory filtering is achieved using an 8-pole Butterworth filter with a corner frequency (3 db point) of 7.0 ± 0.5 CPS. The filter is flat within $\pm 0.75\%$ from DC to 0.5 CPS, $\pm 1.5\%$ from 0.5 CPS to 4 CPS and $\pm 2\%$ from 4 to 5 CPS and has a rolloff of 48 db per octave minimum. Side lobes, beyond the frequency of the theoretically determined 60 db point, are at least -60 db with respect to the pass band out to a frequency of 100 kc.

The outputs of the filters are sampled by a high-level analog multiplexer. All channels are sampled within a 1.0 millisecond period with follow and hold circuitry to provide time correlation between samples within 10 microseconds. The scanning rate is switch-selectable between 20, 25, 40, and 50 scans per second.

The multiplexed analog samples are then digitized to 10-bit binary words with a corresponding resolution of 1 part in 1024 by the analog-to-digital (A-D) converter. Each signal wire pair is multiplexed to the A-D converter as a differential pair. For a 5.0 volt full scale input the A-D conversion accuracy is $\pm 0.05\%$ of full scale $\pm 1/2$ least significant bit.

A word generator is incorporated in the system to produce two parallel 10-bit Barker Code (Reference 6) words for synchronization at the start of each frame. The five channels of digital data appear as the next five words in each frame followed by the time-of-day code as the next three words. The scanning and sampling rates are synchronized with this clock and with the time code generator which outputs time in IRIG-C format for analog recording on the on-board oscillograph. The time code is also recorded on the magnetic tape to facilitate automatic tape search operations at the data processing ground station during preparation of the computer compatible tape for further data analysis. The clock is provided with standby (battery) power which can operate the time code generator for up to 30 minutes during an interruption in primary power.

4. MAGNETIC TAPE RECORDER

The digital instrumentation system output is multiplexed into a 10-bit data word plus a lateral parity and a synchronizing clock bit resulting in a 12-bit parallel format. An Ampex model AR214 magnetic tape recorder used on the previous HICAT Program was modified with an IRIG 16 track digital recording accessory kit. This recorder is capable of recording the digital instrumentation system output for a continuous period of four hours at a tape speed of 3-3/4 inches per second using 1.0 mil thin oxide magnetic recording tape. A tape speed

of 1-7/8 inches per second is also available which increases the packing density to 670 bits per inch. Additionally, the pilot's voice annotation and the IRIG-C time code are recorded on two of the recorder channels using analog techniques.

5. ANALOG RECORDER

A multi-channel oscillograph installed on-board the aircraft, records quick-look data during the HICAT test flights and a portable processor is used to develop the record immediately following the flight at the test site. The outputs of the transducers, after being passed through the PCM system presampling filters, are isolated and padded to a suitable galvanometer recording level at the oscillograph integrated control system panel. All transducers on-board the aircraft are recorded on this unit which is operated throughout each flight. This record provides a very valuable monitor of transducer and system operation for maintenance and trouble-shooting purposes.

6. SYSTEM CONTROL PANELS

A system control panel is mounted in the cockpit permitting pilot control of the PCM system and the magnetic tape recorder. In addition, this control panel contains the 6 digital switches for insertion of ancillary inputs into the digital instrumentation system by the pilot. Cockpit control panels are also provided for the analog recorder and the LN-3 inertial platform.

SECTION IV

PHYSICAL AND ENVIRONMENTAL CHARACTERISTICS

The HICAT instrumentation system operates from standard +28 volt DC aircraft power. The PCM system package is contained within a maximum envelope of 7 inches high by 34.75 inches long by 13.2 inches wide and weighs 143 pounds. The time code generator is 5.0 inches wide by 10.5 inches high by 20.5 inches deep and weighs 26 pounds. The magnetic tape recorder is 27 x 12 x 8 inches in size and weighs 85 pounds. The electronics cabinet has the dimensions of 16 x 8 x 4 inches and weighs 9 pounds. The analog recorder system is 15 x 18 x 40 inches and weighs approximately 150 pounds.

The instrumentation system major components are mounted in the aircraft Q-Bay, with the exception of some signal conditioning units, transducers, and control panels which are located throughout the aircraft.

The system is designed to operate over a temperature range of -10°C to +80°C at an altitude from sea level to 50,000 feet and to withstand a range of temperatures from -55°C to +125°C in a nonoperating condition. The system is also designed to withstand vibration levels of 0.08 inches double amplitude, 10 to 50 CPS and of up to 10 g's random, 50 to 2000 CPS and 3 axis shocks to 30 g's for up to 11 milliseconds, as well as relative humidity up to 100% with sand and dust conditions as encountered in desert areas.

SECTION V

FIELD SUPPORT EQUIPMENT

1. PCM SYSTEM FIELD CHECKOUT UNIT

This unit provides a capability of developing input signals and displaying output data for analysis of the PCM system operation and calibration. The unit is a self-contained checkout package, which connects to the PCM system via cables and test connectors, and is divided into two sections. The analog subsection develops a very accurate reference input, selectable by front panel switching, in conjunction with simulation of source impedance. The second subsection is digital and monitors the final PCM/NRZ-Mark code that drives the Ampex digital tape recorder. A binary light display provides the decoded NRZ-Mark PCM data, selectable by front panel switching for all words in the PCM system format. A test point and power monitor provision is provided and permits the operator to monitor the internal function-ing of the PCM system on suitable auxiliary test equipment such as voltmeters, oscilloscopes, counters, calibration and standards equipment which are stored in the field support unit.

SECTION VI

DATA PROCESSING GROUND STATION

The purpose of the HICAT Data Processing Ground Station is to provide a means to edit airborne digital PCM data recorded on magnetic tape and to convert it into a format com-patible for input into an IBM 7094 scientific computer for further processing.

The Data Processing Ground Station performs the functions of retrieval of data from the airborne magnetic tape, decommutation of data, decimal display, data editing, digital-to-analog conversion with analog display, format conversion, and recording of re-formatted computer compatible output data onto magnetic tape. The ground station block diagram is shown in Figure 7 (References 7, 8, and 9).

1. EQUIPMENT LIST

The complete HICAT Data Processing Ground Station with all peripheral equipment con-sists of the following items:

CEC Model VR-2600 Input Magnetic Tape Reproducer

Astrodata Model 5220-100 IRIG Time Code Translator

Astrodata Model 5224-100 Tape Search and Control Unit

```
          ┌─────────────────────┐
          │   INPUT  DIGITAL    │
          │  MAGNETIC  TAPE     │
          │    TRANSPORT        │
          │  (RAW  DATA  TAPE)  │
          └─────────────────────┘
```

                        ┌─────────────────────┐
                        │   TAPE SEARCH   │
                        │   TIME DISPLAY   │
                        │ AND CONTROL UNIT │
                        └─────────────────────┘

```
┌──────────────┐      ┌──────────────┐
│    VOICE     │      │  REPRODUCE   │
│  ANNOTATION  │      │ ELECTRONICS  │
└──────────────┘      └──────────────┘
```

```
┌──────────────┐      ┌──────────────────┐      ┌──────────────┐
│    VISUAL    │      │      PCM         │      │ DIGITAL-TO-  │
│   DISPLAYS   │      │  DECOMMUTATION   │      │   ANALOG     │
└──────────────┘      │   SUBSYSTEM      │      │  CONVERTERS  │
                      └──────────────────┘      └──────────────┘
```

```
┌──────────────┐                                ┌──────────────┐
│    PATCH     │                                │ OSCILLOGRAPH │
│     AND      │                                │   RECORDER   │
│   CONTROL    │                                └──────────────┘
└──────────────┘
```

```
          ┌─────────────────────┐
          │  BUFFER - FORMATTER  │
          │     SUBSYSTEM        │
          └─────────────────────┘
```

```
          ┌─────────────────────┐
          │  OUTPUT  DIGITAL    │
          │  MAGNETIC  TAPE     │
          │    TRANSPORT        │
          │  (COMPUTER  TAPE)   │
          └─────────────────────┘
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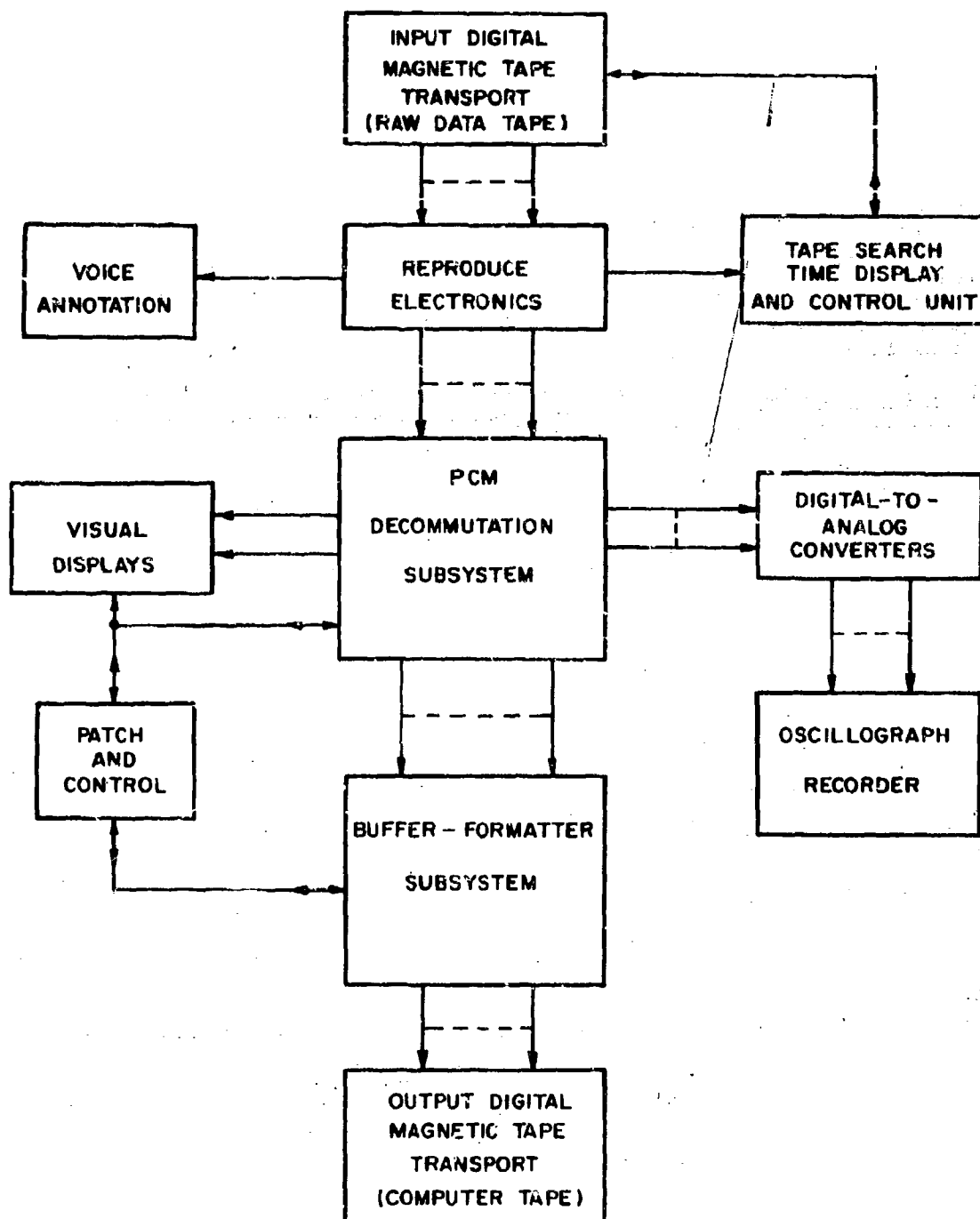
Figure 7   HICAT Data Processing Ground Station

LEC Model PCD 101A PCM Telemetry Decommutation and Computer Tape Buffer-Formatter System

CEC Model 5-133 Direct Print Oscillograph Recorder (Lockheed-owned)

IBM Model 729 V Magnetic Tape Recorder (Leased from IBM)

2. INPUT DATA

The airborne data, which is digitally recorded on magnetic tape at 3-3/4 inches per second using parallel format PCM techniques, is played back on the CEC Model VR-2600 Magnetic Tape Reproducer at 60 inches per second and input into the ground station permitting data conversion at 16 times the real-time recording speed. The HICAT digital input format is a parallel 12-bit format with a 10-bit data word, a lateral parity bit and a synchronizing clock bit. Additionally, pilot's voice annotation and IRIG-C time code are recorded on two of the remaining 4 tracks using analog techniques.

The HICAT recorded frame length is 50 words with 2 Barker Code words for synchronization, 5 words for reference data, 3 words for time-of-day code and 40 words available for data.

3. INPUT CAPABILITES

The system will accept the parallel data inputs at a rate of 36,000 words per second for an 11-bit word. The input format, including the input coding, word length, frame length, and frame synchronization is programmable on a removable patch board. The system is capable of handling serial or parallel data in NRZ (C) or RZ format. The word length is programmable from 4 to 16 bits. Prime frame length is programmable from 2 to 399 words. The frame synchronization word is programmable from 4 to 32 bits in the search mode. In check and lock mode, the frame synchronization is programmable as one, two, or three adjacent words.

4. INPUT CONTROL

The input from the VR-2600 Tape Reproducer is controlled by the Astrodata Tape Search and Control Unit and the Time Code Translator. By means of thumbwheel switches, the start and stop times for the selected data to be processed through the Ground Station may be manually set into the Control Unit. The data to be processed through the Ground Station is visually selected from the airborne-recorded oscillograph record. IRIG-C time is recorded on the oscillograph record to provide the start/stop time inputs to the Control Unit. The IRIG-C time code recorded by analog techniques on a separate track on the tape is input to the Time Code Translator where it is translated to a parallel BCD time code which is input to the Tape Search and Control Unit. A visual display presents the translated time from the input tape in days, hours, minutes, and seconds for monitoring purposes. When the search mode is put into operation, the tape time, as received from the Time Code Translator, is constantly compared with the run start time set in by the thumbwheel switch on the Tape Search and Control Unit. When equivalent time is achieved in the parallel comparator, a start pulse initiates the transfer of data from the input tape to the level shifting amplifiers in the Ground Station. Data is read into the Ground Station until the time comparison logic detects equivalence between tape time and run stop time as manually inserted with the thumbwheel switches. A stop pulse is then generated to stop the transfer of data from the input tape.

5. SERIAL CONVERSION

Parallel data from the input tape are amplified and then input into the shift register where a 500 kc clock pulses to shift the parallel data bits out of the register in serial fashion.

16

6. DECOMMUTATION

The serial word-bit patterns, both synchronization and data, are clocked into the decommutator. The frame synchronization pattern preceding the data words is compared to a patch synchronization code. The input serial data train is converted to continuously available parallel output data. These data words are gated to the decommutator output subsystem by the decommutator control logic which is dependent upon the patched word, synchronization, and frame format.

7. DECOMMUTATOR OUTPUT SUBSYSTEMS

There are three output subsystems which provide analog, visual and digital outputs simultaneously; the Digital-to-Analog Conversion Subsystem, the Decimal Display Output Subsystem, and the Buffer-Formatter Subsystem.

8. DIGITAL-ANALOG CONVERTERS

There are fourteen storage registers and fourteen digital-analog converters which simultaneously provide 14 DC analog outputs selected from any of the digital data words by means of thumbwheel switches on the Control Unit. The analog signals are input to a CEC Direct Write Oscillograph Recorder for immediate and simultaneous analog display of up to 14 data channels plus IRIG-C time. This analog record provides a means of monitoring the playback of the data, for analysis and editing and for troubleshooting. The eight most significant bits from the decommutator output MSB bus (Most Significant Bit) are parallel-connected to each of the 14 independent digital-analog converters.

9. DECIMAL DISPLAY

The decimal display provides a visual digital monitoring of any two channels simultaneously. Two four-decade decimal displays are provided which simultaneously convert the 13 most-significant bits of any pair of words from binary to decimal. There are two display modes: a "Read Continuous" and "Read Hold". "Read Continuous" is automatically updated. "Read Hold" may be manually updated. Channels are selectable by means of thumbwheel switches on the Control Unit.

10. BUFFER-FORMATTER

The buffer-formatter assembles the decommutated data into the standard IBM gapped format.

The buffer-formatter receives words programmable from 4 to 14 bits from the decommutator output MSB bus. In addition, there are 24 bits input to the buffer-formatter for run identification information which are input manually by means of thumbwheel switches on the Control Unit. The run identification data are entered before the first data character in each record.

The core memory has a capacity of 4096 7-bit characters. Data sets are gated into the memory in 6-bit groups with each group becoming one memory character. Each character is accompanied by a parity bit (odd parity) during entry into memory which is generated at the input data gate and monitored during the memory read-cycle at the outer register. Data are loaded into the "input side" of memory until the number of 6-bit words that are stored is equivalent in number to the selected record length. Record lengths of up to 2048 6-bit characters may be selected by means of octal switches at the rear of the control panel. The HICAT record length is 1446 characters.

17

When a full record length is achieved in the input storage register, the output storage register dumps the stored record. The record in the input storage register is transferred to the output storage register and new data are loaded into the input storage register to complete the cycle. Memory cycle time is 2.0 microseconds.

11. DATA OUTPUT

Data records are output to the IBM 729 V Tape Recorder under automatic control of the buffer-formatter control logic. The control logic further provides a data reset-to-zero for decommutator parity errors and a parity check for core memory operation. Data are stored on 7 track magnetic tape in computer compatible format at a recording density of 800 bits per inch per track at a tape speed of 75 inches per second. The format consists of parallel 6-bit characters with lateral and longitudinal parity, a 3/4 inch inter-record gap and an end-of-file mark and gap. Each 10-bit word plus 2 dummy bits is formatted into 2 parallel, 6-bit characters.

SECTION VII

DATA PROCESSING AND ANALYSIS

1. DATA PROCESSING

The computer compatible tapes will be processed as diagrammed in Figures 8 through 10 to obtain the following:

1. Filtered time histories of all measured quantities as well as derived flight parameters such as Mach number and true airspeed.

2. Equivalent derived gust velocity (U_{d_e}).

3. Vertical and lateral gust velocity time histories.

4. Peak counts and exceedances.

5. Power spectra and associated statistical functions (for example, cross spectra, cross correlation functions, coherence functions).

6. Cumulative probability distributions of RMS gust velocities.

The processing described above will be performed using the programs written for the initial phase of the HICAT Program. Where this is not feasible, new programs based upon those described will be written. Because long wave turbulence requires long data samples for analyses, it is anticipated that the gust velocity power spectra will be generated over two overlapping frequency ranges.
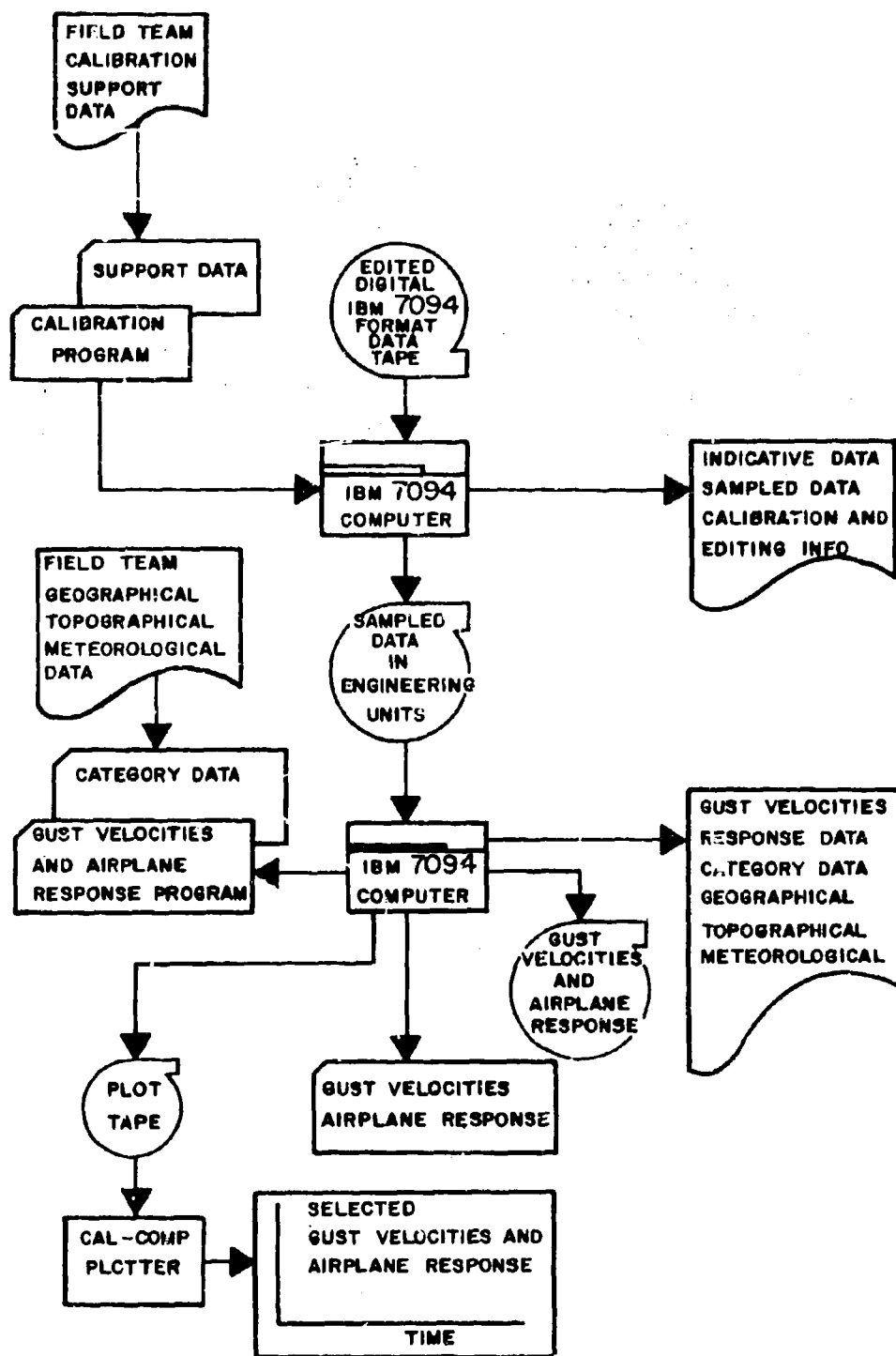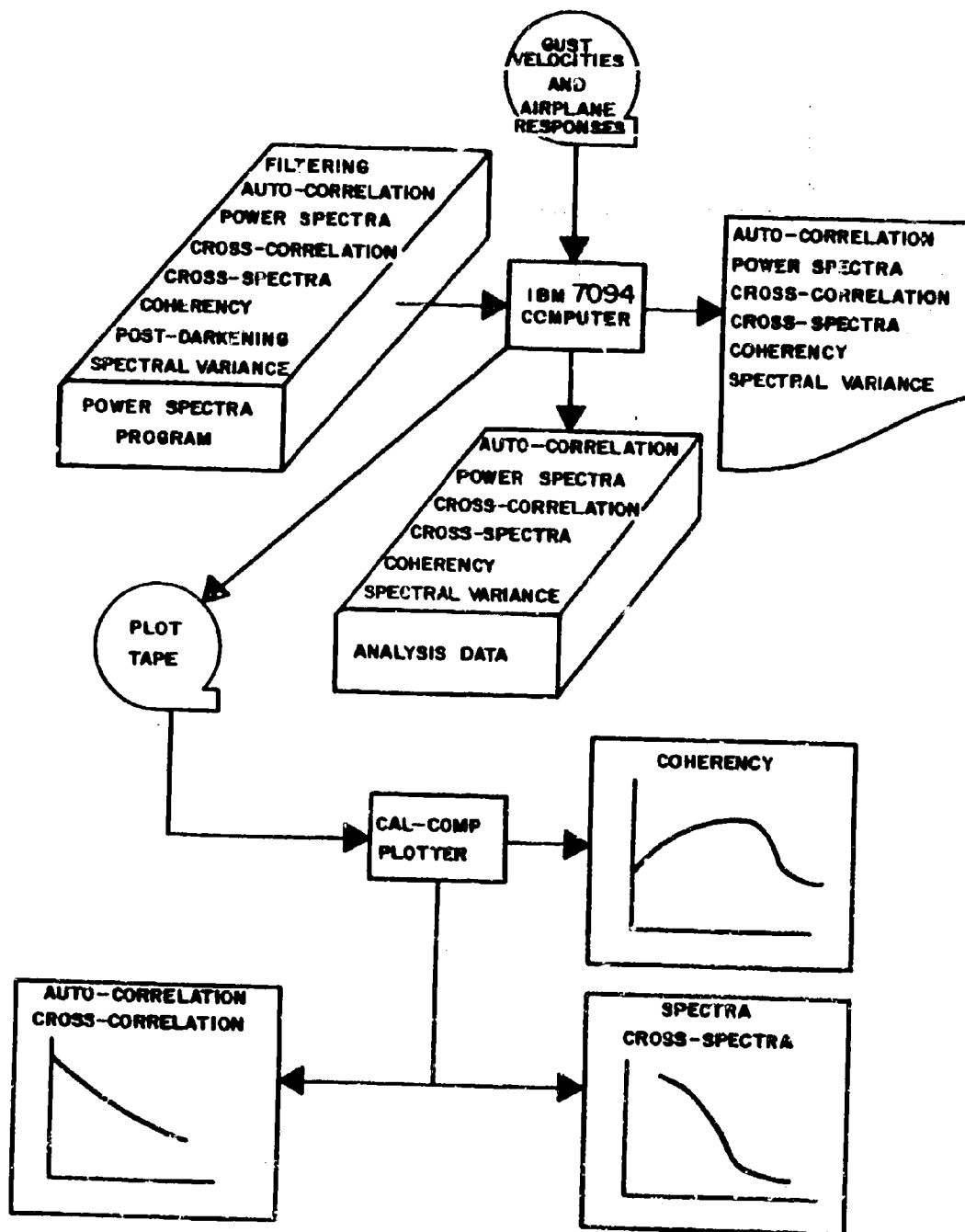
18

Figure 8   Data Processing Flow Chart

Figure 9   Data Processing Flow Chart
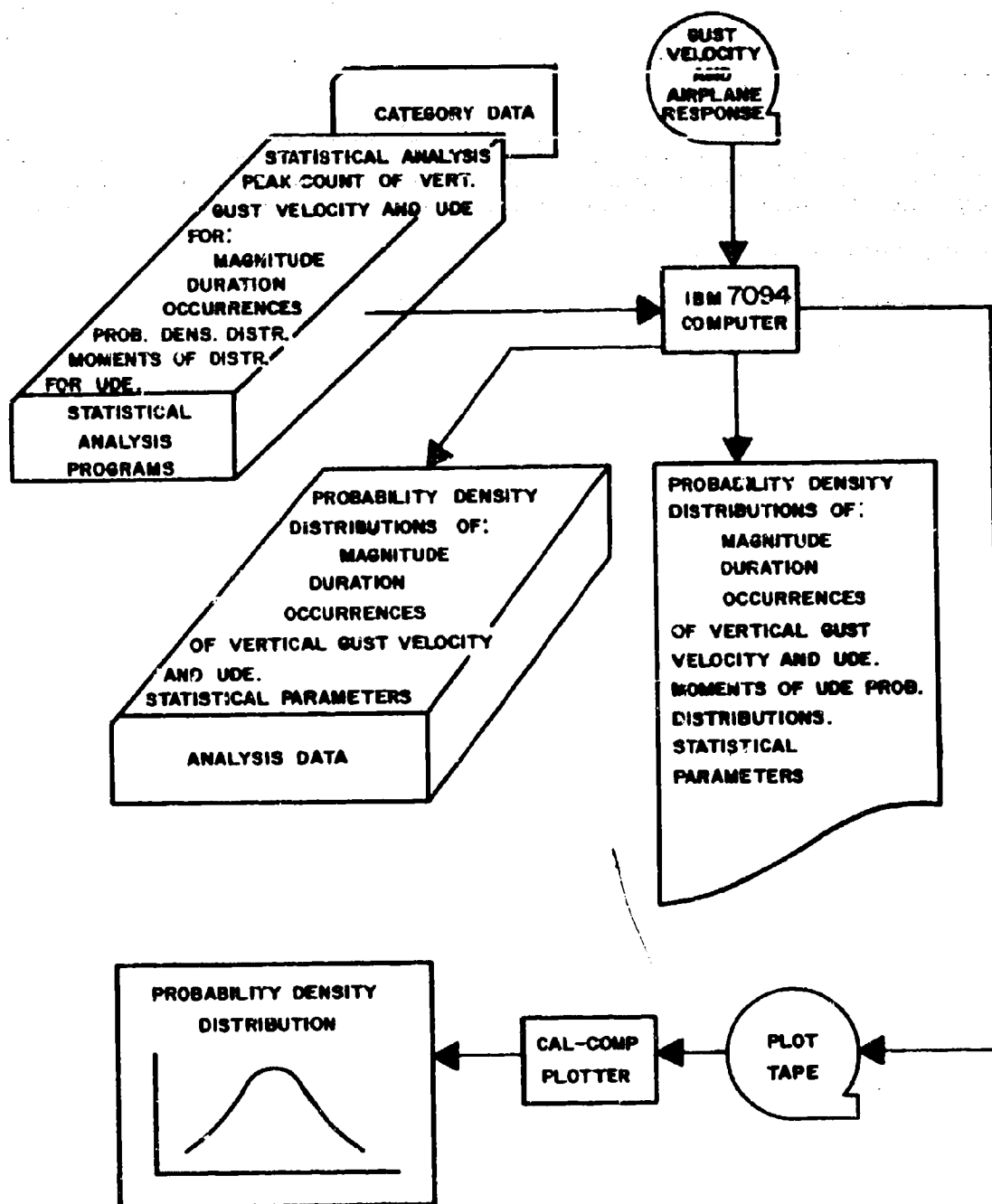
20

AFFDL-TR-67-1

Figure 10   Data Processing Flow Chart

21

2. ANALYSIS

The gust velocity analysis will be performed essentially as described in the "HICAT Program Preliminary Data Reduction and Analysis Report" (Reference 10). Though this report was written during the first phase of HICAT, the Methods Analysis Section is completely applicable to this program.

The long waves to be measured in the program will require the analysis of long samples of data. This may require, as stated in the discussion of the data processing, that the power spectra be computed in two frequency ranges and then overlapped. Other than applying the criterion that the overlapped sections agree, no new analysis methods will be required.

The analysis will consist of the following:

1.   Examination of raw and filtered measurement time histories and the computed gust velocity time histories.

2.   Evaluation of gust velocity power spectra particularly with respect to slope and scale of turbulence.

3.   Evaluation of gust velocity peak count and exceedance curves.

4.   Comparison of RMS level statistics and evaluation of cumulative probability distributions of RMS gust velocities.

5.   Evaluation and comparison of derived equivalent gust velocities U_{d_e}) with those of NASA-TN D 548 (Reference 11).

6.   Categorizing and correlation of data taking into account the meteorological factors involved.

REFERENCES

1. *Development Plan*, Advanced Development Program, ADP 682E, Air Force Systems Command. March 1966.

2. Walter Crooks, *High Altitude Clear Air Turbulence*, AFFDL-TR-65-144, Sept 65, Unclassified.

3. W. M. Crooks, *Derivation of Gust Velocity Equations*, Lockheed-California Co., unpublished, Unclassified.

4. R. C. Quist, *Instrumentation Report for Redirected HICAT Program*, Lockheed Report 19409, Jan 10, 1966, Unclassified.

5. W. M. Crooks, *A Fixed Vane Sensor for Measuring Turbulent Air Flows*, ISA Tenth Nat. Aerospace Instrumentation Symposium, 5 May 1964, Unclassified.

6. Willis Jackson, *Communication Theory*, Academic Press, London 1953.

7. R. C. Quist, *Modification and Capability Report for HICAT Data Processing Ground Station*, Lockheed Report 19478, Feb 9, 1966, Unclassified.

8. *System Checkout Report for HICAT Data Processing Ground Station*, Lockheed Report 451276, Feb 9, 1966, Unclassified.

9. *HICAT PCM Telemetry Ground Station Operation and Maintenance Instructions*, Lockheed Report 451276, Vol I and II, Feb 9, 1966, Unclassified.

10. C. B. Fabian, *HICAT Program Preliminary Data Reduction and Analysis Methods*, Lockheed Report 17696, 31 Mar 64, Unclassified.

11. Thomas L. Coleman, and Ray Steiner, *Atmospheric Turbulence Measurement Obtained From Airplane Operations at Altitudes Between 20,000 and 75,000 Feet for Several Areas in the Northern Hemisphere*, NASA TN D-548, Oct 60, Unclassified.

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13. ABSTRACT

The purpose of this report is to provide a synopsis of the data system designed to measure, record, and process High Altitude Critical Atmospheric Turbulence (HICAT) data.

The HICAT Project is to measure gust velocity components in the altitude range of 40 to 70 thousand feet in several world areas. The goal is a statistical definition of the "roughness" of the atmosphere which can be applied to design requirements for advanced aircraft structures.

A Pulse Code Modulation airborne system is described. Highly accurate sensors and components, including an inertial platform, are used aboard a WU-2 test aircraft in an attempt to resolve fine scale forces, accelerations and aircraft motions in the atmospheric gust field. The magnetic tapes and other pertinent information are sent to a data processing ground station for generation of a computer-compatible tape, processing, and detailed analysis. Power spectral functions of the gust components are of major interest. Output data are correlated with meteorological and geographical data associated with the test site.

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